

Micromachining with both Dry and Wet Etching

Silicon optical bench chips often have anisotropically etched V-grooves for holding optical fibers or other components. Also, SiOB chips can have dicing saw cuts that function as fiber stops, thereby providing passive longitudinal alignment for an optical fiber. Such optical bench chips are well known in the art.

In some cases, it is not desirable or practical to have dicing saw cuts. Particularly, cuts can be undesirable because they typically must extend across an entire wafer.

It would be an advance in the art to provide fiber stops in optical bench chips without requiring dicing saw cuts.

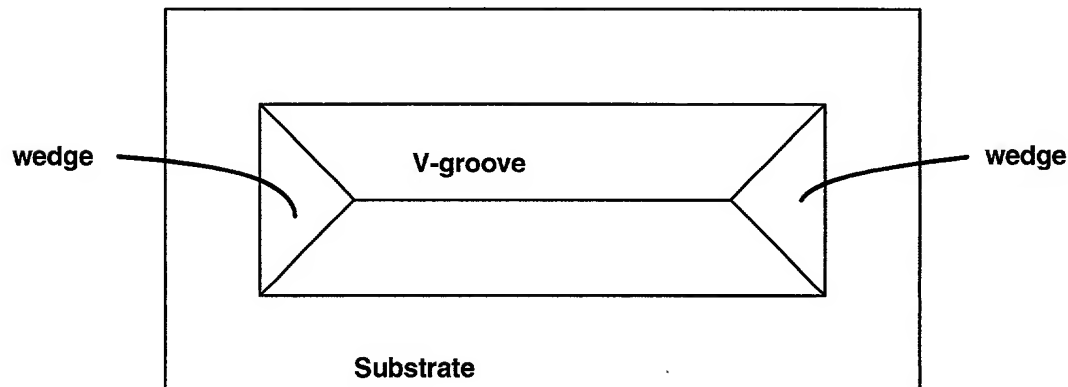
Also, it would be an advance in the art of micromachining to provide a wider array of precision made structures. particularly, it would be advance to combine multiple micromachining techniques to provide unusual, useful structures.

The Present Invention

In the present invention, a pit is first made by dry anisotropic etching. Then, the surfaces (sidewall and bottom) of the pit are masked (e.g. with CVD silicon nitride, CVD SiO₂, or thermal oxide). The mask is resistant to an anisotropic etch (e.g, KOH, EDP). Then, the surface of the substrate is anisotropically wet etched. Finally, the mask material in the dry pit is removed. The mask removal step is optional.

The method of the present invention can be used to make a very wide variety of micro-machined structures such as optical submounts, sensors, and the like.

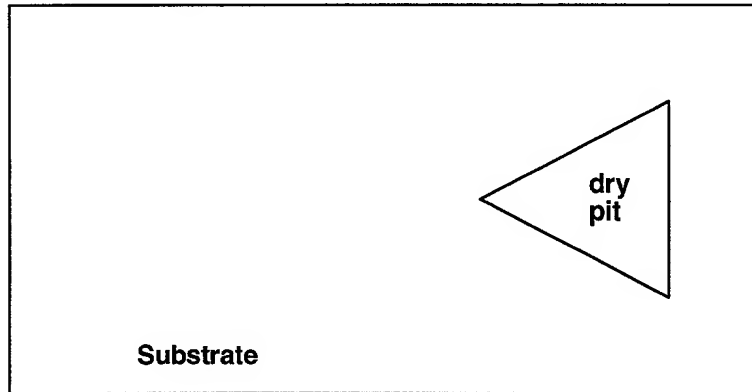
The present invention is particularly useful for its ability to eliminate the 'wedge' that forms at the end of an anisotropically etched V-groove. Such a wedge is shown below.



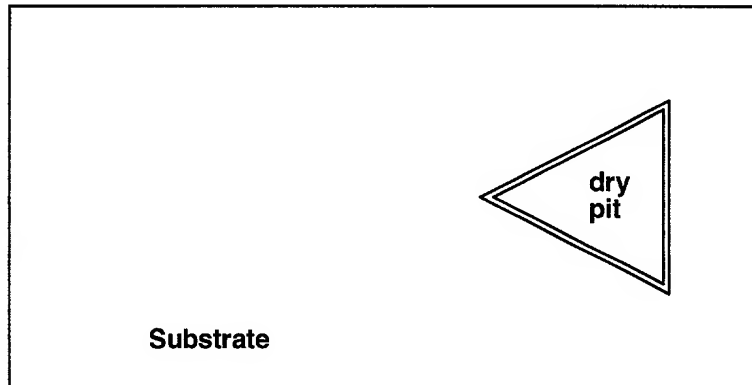
Wedges are often undesirable in optical subassemblies because they can block the optical path of light from a fiber disposed in the V-groove. Also, wedges function poorly as optical fiber stops, since they are sloped.

An embodiment of the present invention is illustrated below.

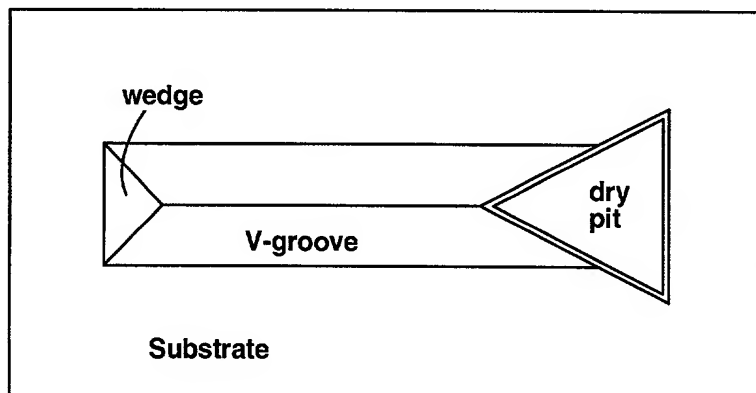
- 1) A pit is dry etched into a silicon substrate. The dry etched pit (dry pit) is optionally made by high-aspect ratio dry etching. The dry pit may have vertical or sloped sidewalls.



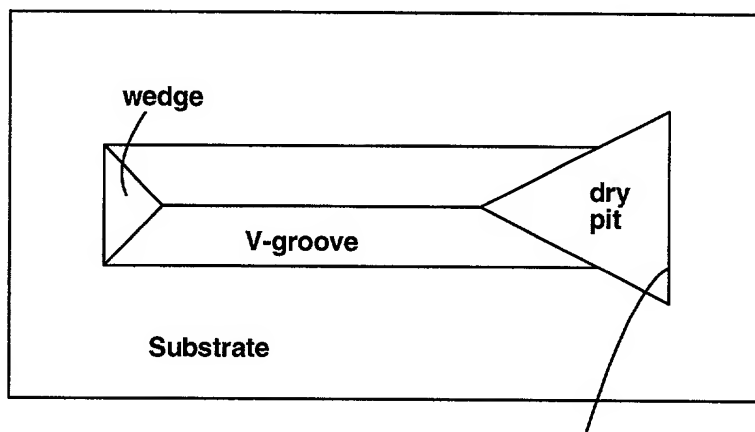
- 2) The dry pit is coated with a mask material that is resistant to anisotropic wet etchants (e.g. KOH, EDP). The mask material can be CVD silicon nitride, CVD SiO₂, or thermal oxide, for example. The top surface can also be coated, but this is optional.



- 3)** The top surface is wet etched to form a wet-etched pit (a wet pit) or a V-groove. The dry pit removed the material that would have formed the wedge in the V-groove. At this point, there may be a free-standing thin film from the sidewall of the dry pit that was exposed during the wet etch. The free-standing thin film is seen edge-on in this top-view. The dry pit should be deep enough so that it is not undercut by the wet etching.



- 4)** The dry pit mask material (including the freestanding thin film) are removed. The V-groove does not have a wedge at the end with the dry pit. The dry pit may function as a fiber stop, since the sidewalls of the dry pit can be vertical.

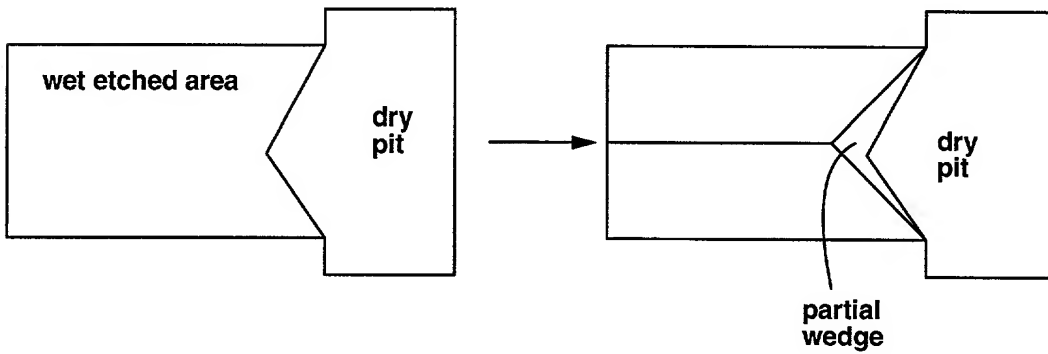
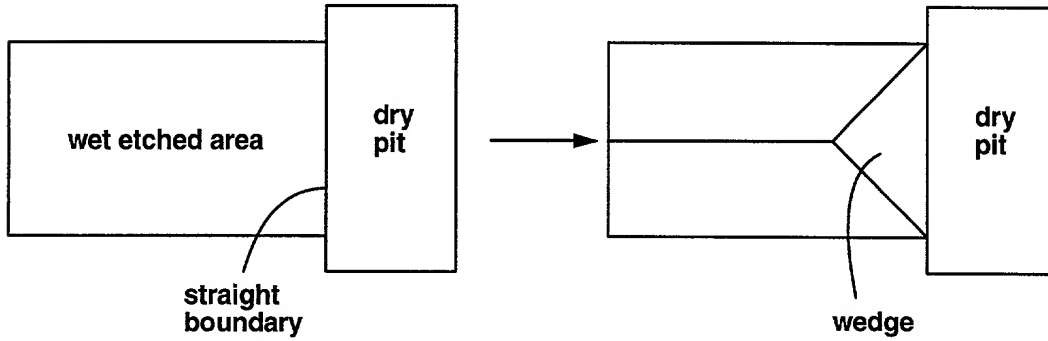


Vertical sidewall that can function as a fiber stop

A distinct advantage of the dry pit fiber stop is that a dicing saw cut is not necessary. In many prior art subassemblies, a dicing saw cut is made across the substrate, and the sidewall of the dicing saw cut functions as a fiber stop. Dicing saw cuts have the disadvantages that 1) they typically must extend across the entire wafer, 2) they are rough and produce particle contaminants, 3) they provide only a limited number of shapes for a fiber stop 4) they create an opening that must be sealed in hermetic packages where the substrate is part of the package.

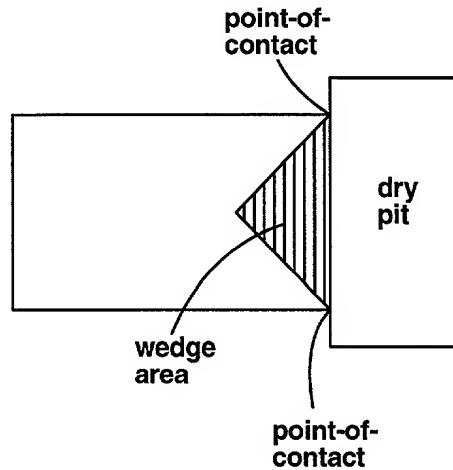
In the present invention, the dry pit preferably is shaped to remove the wedge. Particularly, the dry pit should circumscribe the area of the wedge

A dry pit with a straight boundary adjacent to the wet etched area will produce a wedge:

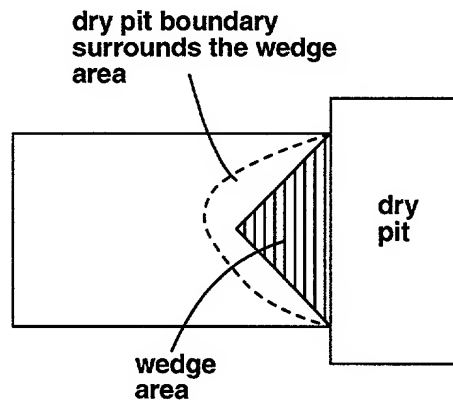


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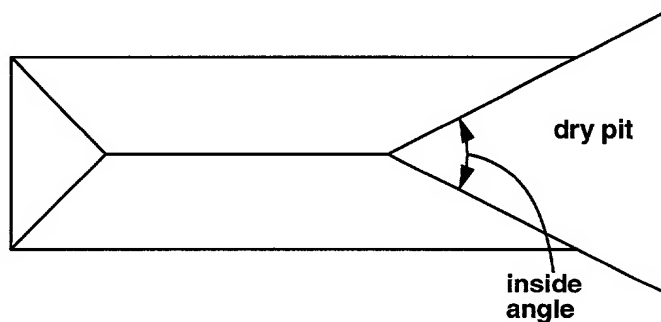
In order to completely remove the wedge, the wedge area must be completely circumscribed by the dry pit. The wedge area is defined by the points-of-contact between the wet etched area and the dry pit. The points-of-contact are shown on the figure below. In a top-view, wedges are always 90-45-45 triangles. The points-of-contact are always located at the 45-degree vertices (as viewed in a top view).



So, in the present invention, the wedge can be completely removed by shaping the dry pit so that it surrounds the wedge area, where the wedge area is defined by the points-of-contact.

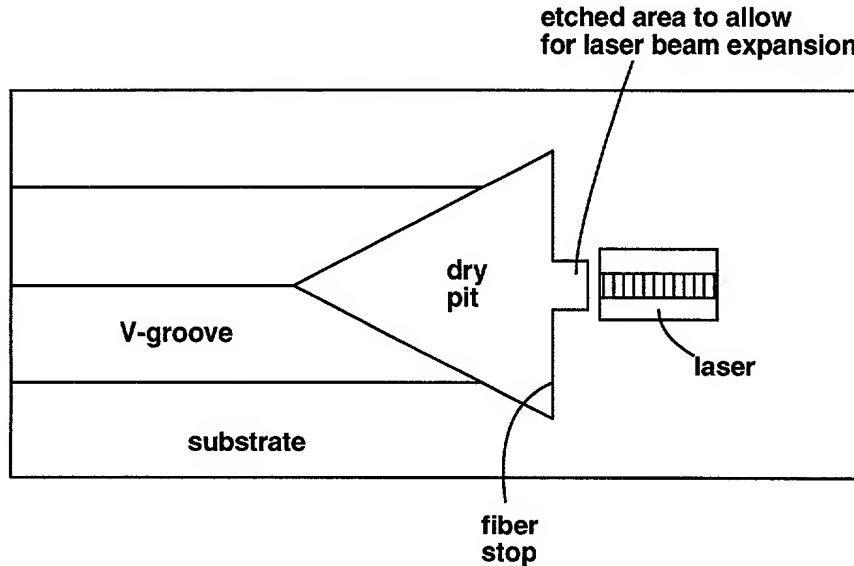


Complete elimination of the wedge can thus be assured by making a triangularly-shaped dry pit with an inside angled of less than 90 degrees., centered on the V-groove.

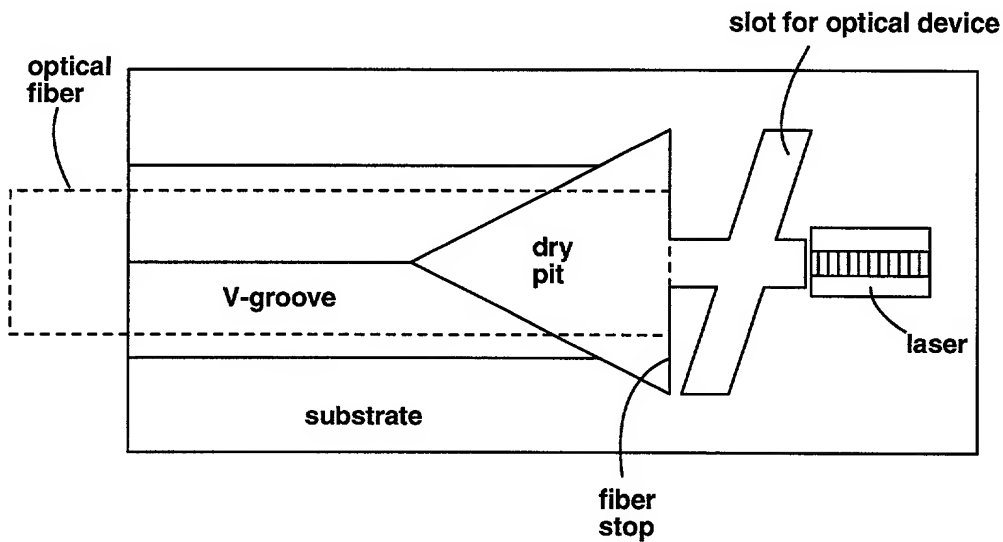


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In a particularly useful embodiment of the invention, an optical subassembly is provided with a V-groove for a fiber, a dry pit with a fiber stop, and a laser mount (e.g. solder pads) for a laser. The dry pit can include an etched area to allow for beam expansion. An advantage of this device is that a dicing saw cut is not required for a fiber stop.

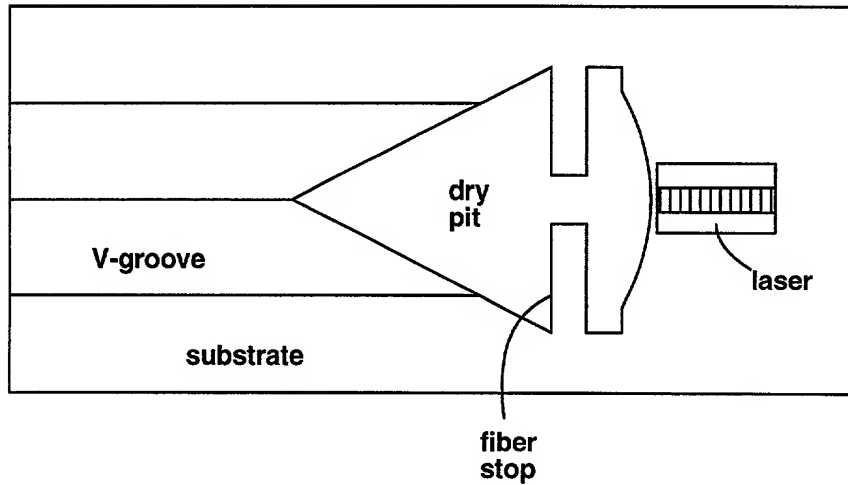


In another embodiment, an additional slot is provided for an optical device (e.g. a filter or lens). The slot can be angled as shown.



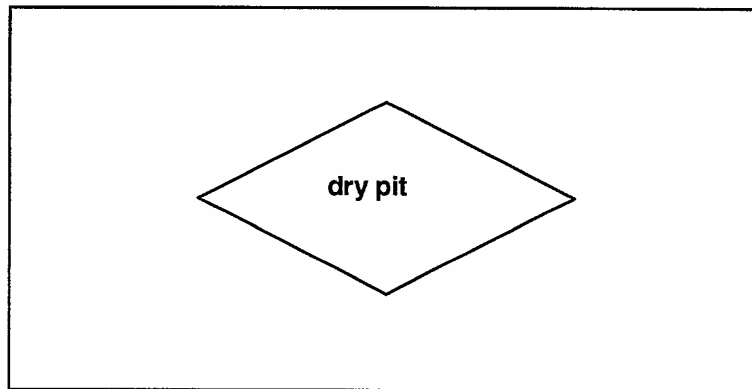
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The slot can also have a lens shape to fit a lens.



The present invention can also be used to join two V-grooves having different sizes. If two different V-grooves are joined, rapid undercut etching occurs. Mask design with corner compensation is used to correct for undercut etching.

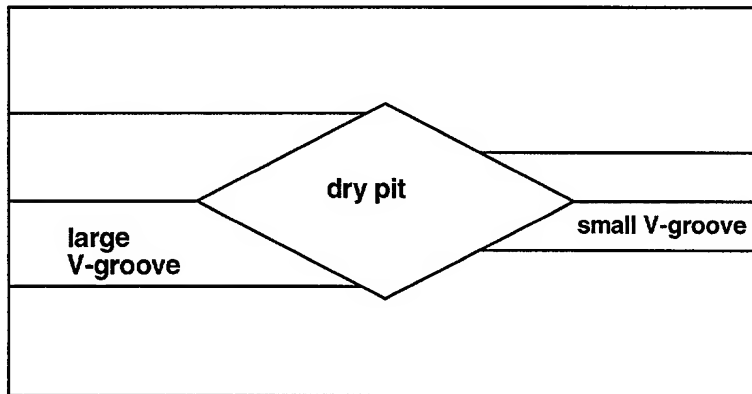
- 1) To join two different-sized V-grooves, a dry pit is formed at the area of intersection. The dry pit may have a diamond shape. the dry pit is coated with a mask material.



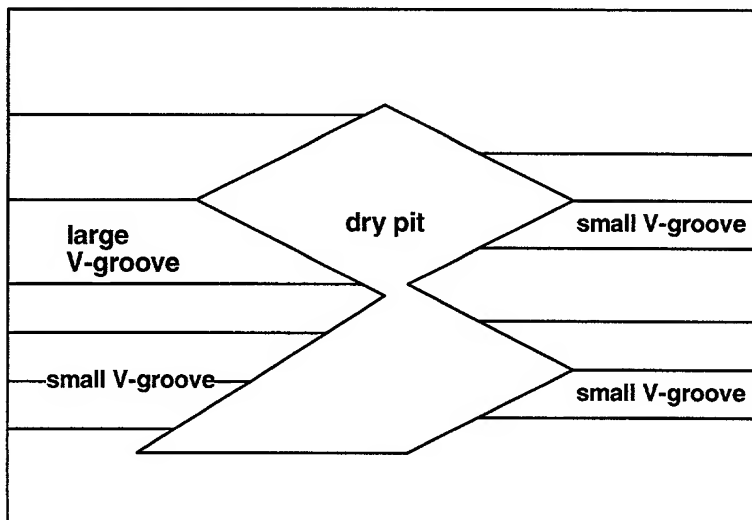
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2)

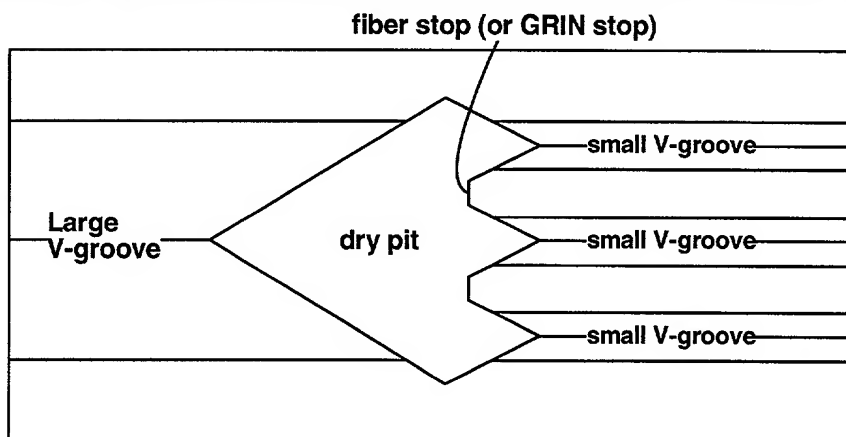
V-grooves are formed aligned with the dry pit. The V-grooves can have any width up to the width of the dry pit. Undercutetching will not occur because the sidewalls of the dry pit protect the silicon. The large V-groove and small V-groove in the figure below are 'in-line'.



The dry pit can be shaped to accomodate multiple fibers, GRIN lenses and the like:

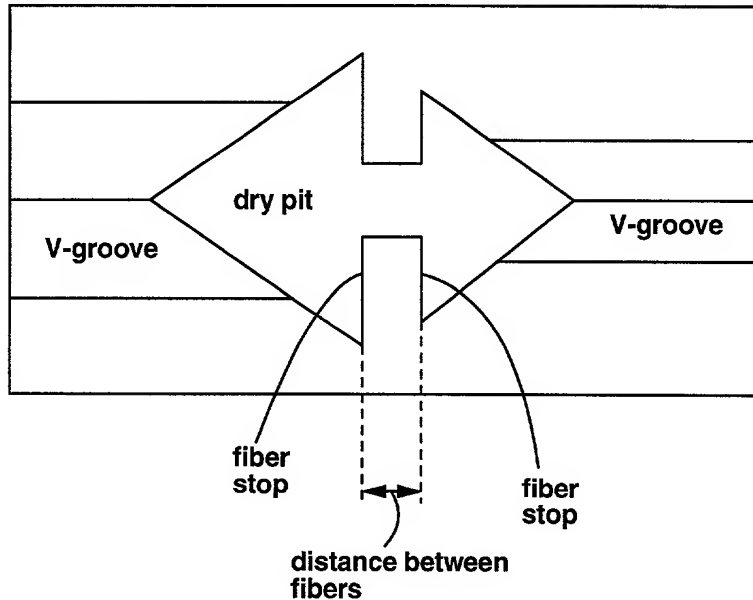


In the figure below, the middle small V-groove is in-line with the large V-groove.

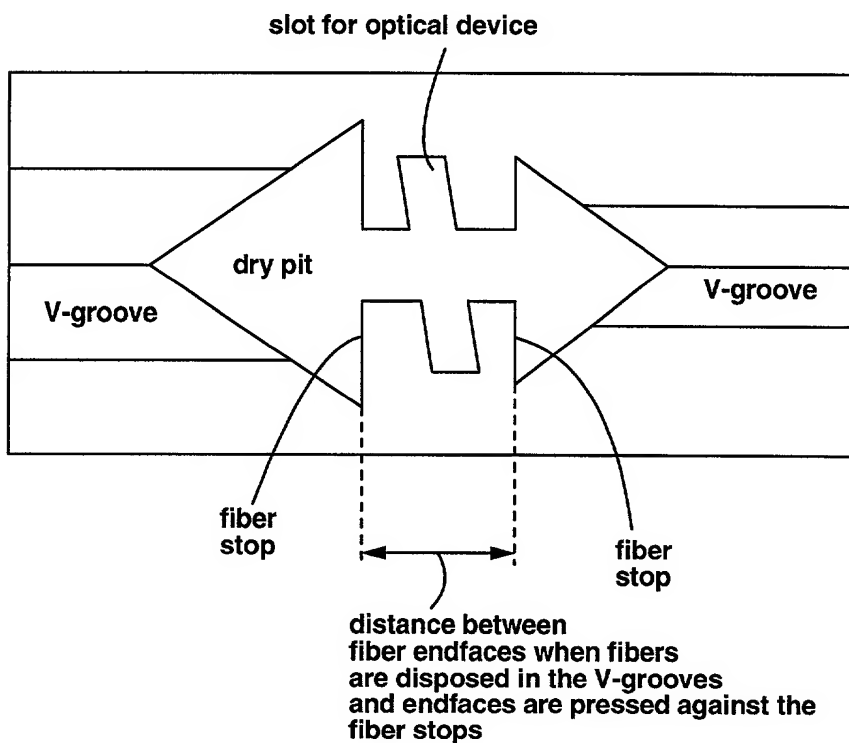


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Also, the dry pit can have built-in fiber stops. Built in fiber stops can provide an accurate distance between fibers disposed in the V-grooves.



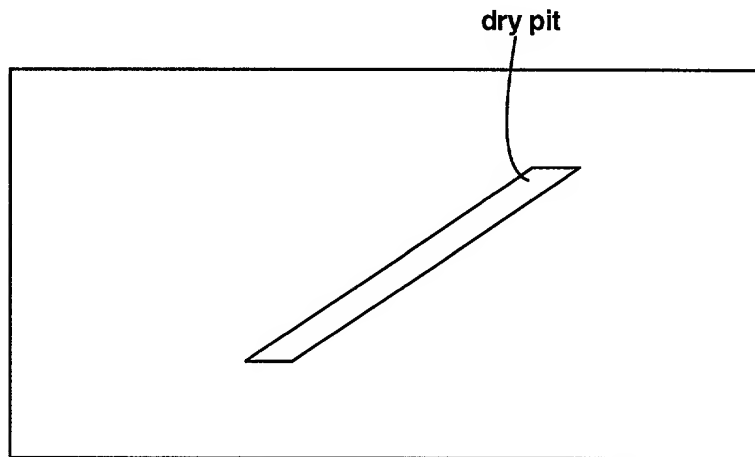
Also, if optical devices (e.g. filters, lenses) are desired between the fibers, a slot can be provided in the dry pit. The slot can be provided between the fiber stops, for example.



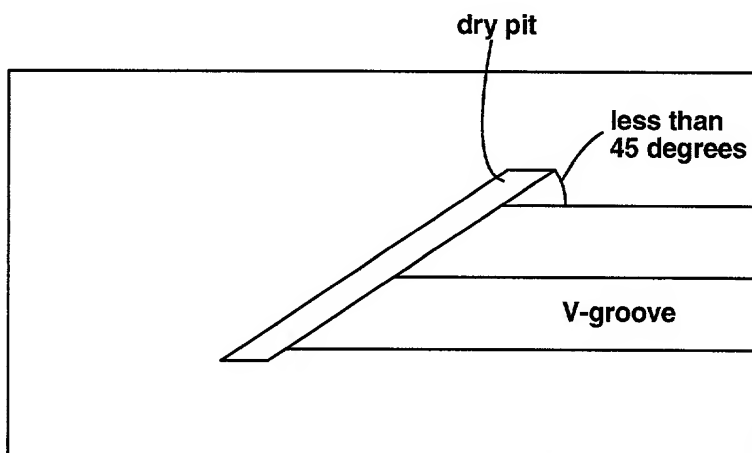
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In yet another embodiment of the invention, two V-grooves are joined by an angled dry pit. The dry pit does not need to be a diamond shape or a triangle. In the case of an angled dry pit, the dry pit should be angled at greater than 45 degrees with respect to the V-grooves.

- 1) Form a long dry pit at an angle. The dry pit can be very narrow compared to the width of the V-grooves to be formed (e.g. the dry pit can be 1/20 as wide as the V-grooves). As before, the dry pit is conformally masked.

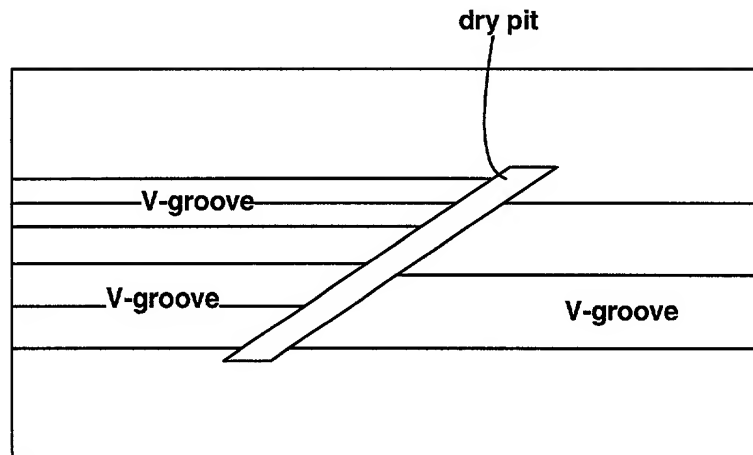


- 2) The V-grooves are etched. If the dry pit is angled at less than 45 with respect to the V-groove length, then the wedges will not form in the V-grooves.

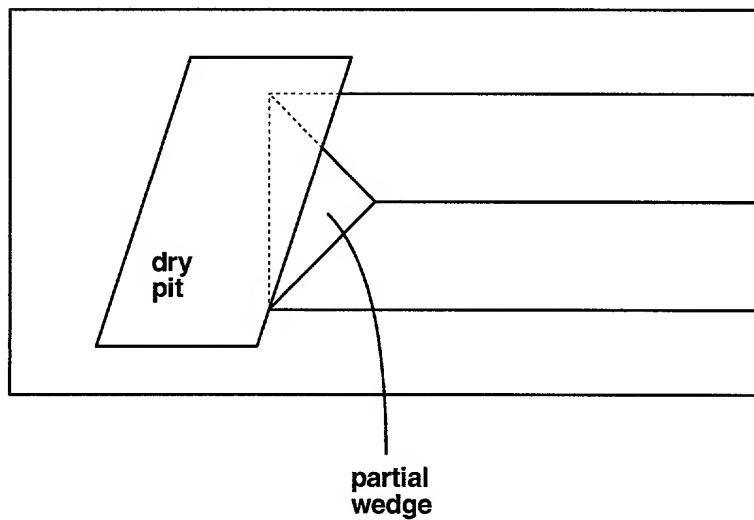


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Any number of V-grooves can be created, and the V-grooves can have different sizes.



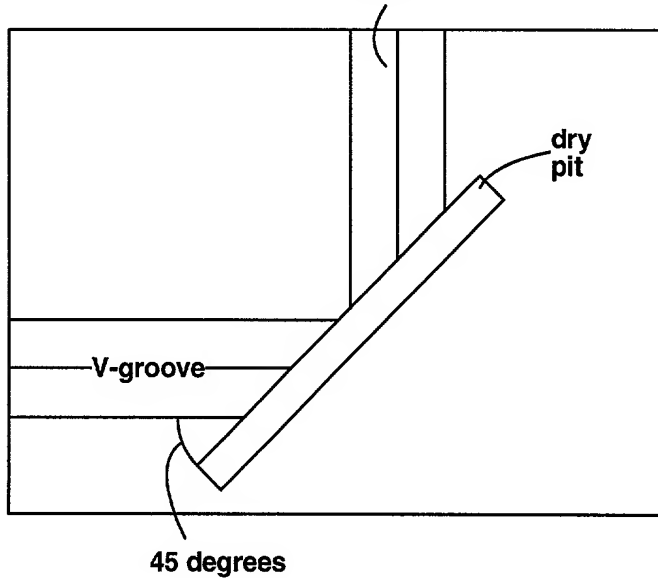
If the dry pit is angled at less than 45 degrees, then a partial wedge will be created.



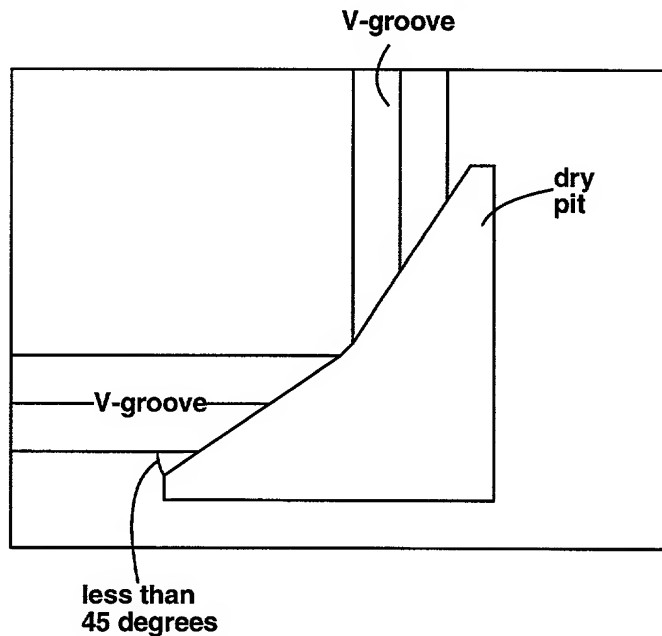
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V-grooves can be aligned at right angles. A dry pit prevents the formation of wedges. The V-grooves can intersect the dry pit at exactly 45 degrees, but this is not preferred. If wedges are not wanted, then the dry pit should be shaped so that all V-grooves intersect the dry pit at less than 45 degrees.

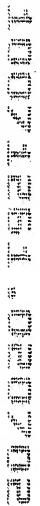
A 45 degree dry pit:
V-groove



In the embodiment below, the dry pit intersects each V-groove at a angle slightly less than 45 degrees so that wedges are not formed.



Variable	Mean	SD	Min	Max
Age	38.5	12.5	20	65
Gender	Male	Female		
Marital status	Married	Single		
Education	High school	College		
Occupation	Manager	Worker		
Income	\$10,000	\$20,000		
Health status	Good	Poor		
Smoking status	Smoker	Non-smoker		
Alcohol consumption	Regular	Occasional		
Exercise frequency	Weekly	Monthly		
Stress level	High	Low		
Family size	2	3		
Home ownership	Owner	Renter		
Commute time	30 min	45 min		
Neighborhood safety	Safe	Unsafe		
Public transportation	Used	Not used		
Crime rate	Low	High		
Property taxes	Low	High		
Quality of schools	Good	Poor		
Local amenities	Many	Few		
Overall satisfaction	High	Low		

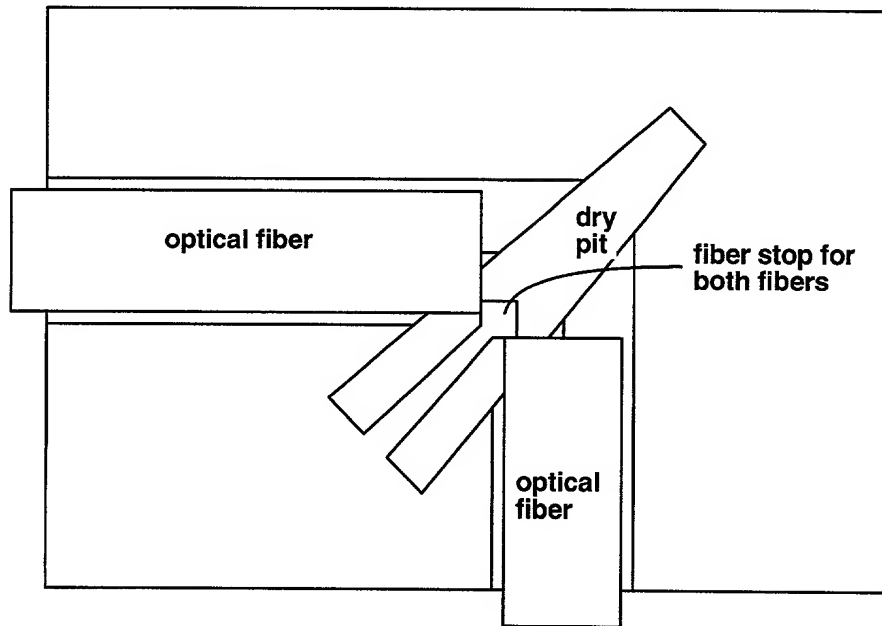


Variable	Mean	SD	Min	Max
Age	38.5	12.5	20	65
Gender	Male	Female		
Marital status	Married	Single		
Education	High school	College		
Occupation	Manager	Worker		
Income	\$10,000	\$20,000		
Health status	Good	Poor		
Smoking status	Smoker	Non-smoker		
Alcohol consumption	Regular	Occasional		
Exercise frequency	Weekly	Monthly		
Stress level	High	Low		
Family size	2	3		
Home ownership	Owner	Renter		
Commute time	30 min	45 min		
Neighborhood safety	Safe	Unsafe		
Public transportation	Used	Not used		
Crime rate	Low	High		
Property taxes	Low	High		
Quality of schools	Good	Poor		
Local amenities	Many	Few		
Overall satisfaction	High	Low		

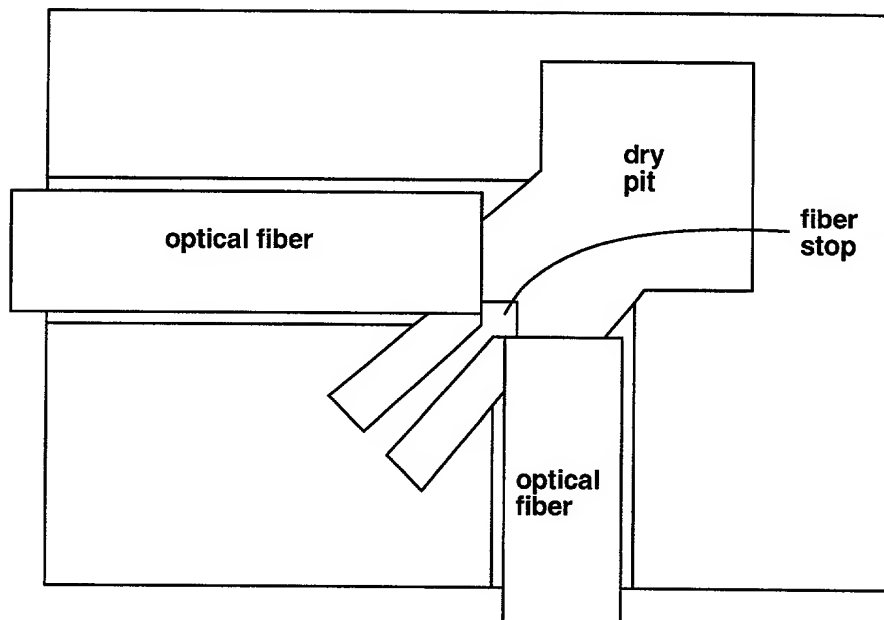


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The dry pit can have a post that functions as a fiber stop for both fibers. Optical devices can be disposed in the dry pit.

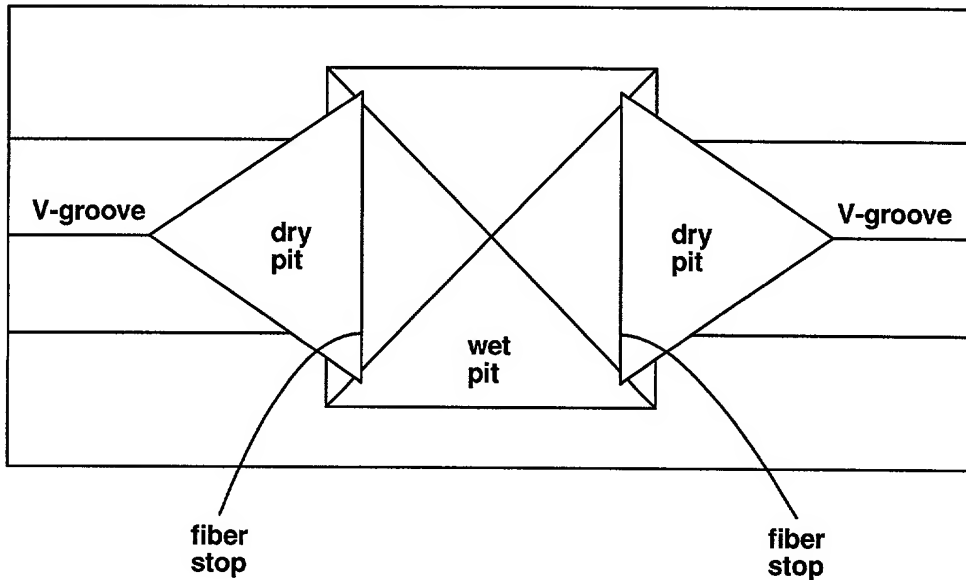


The dry pit can be enlarged to provide space for optical devices. The dry pit should be designed so that wedges are avoided, or so that wedges are so small that they do not contact the optical fibers.

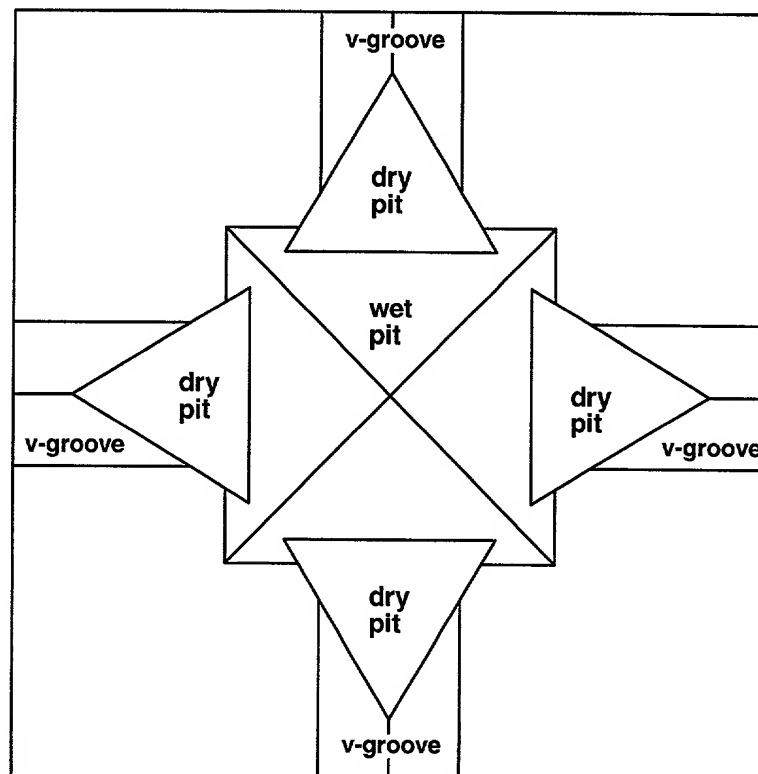


The present invention is also useful for subassemblies having both V-grooves and wet etched pits. Optical fibers can go into the V-grooves, and ball lenses can go into the wet pits. The dry pits of the present invention assure that an optical path between the V-groove and wet pit is not blocked by a wedge.

Below is a device that can hold a fiber-lens-fiber arrangement. Fiber stops are provided for the fibers, and the wet pit hold the ball lens. Of course, optical devices other than ball lenses can be disposed in the wet pit.

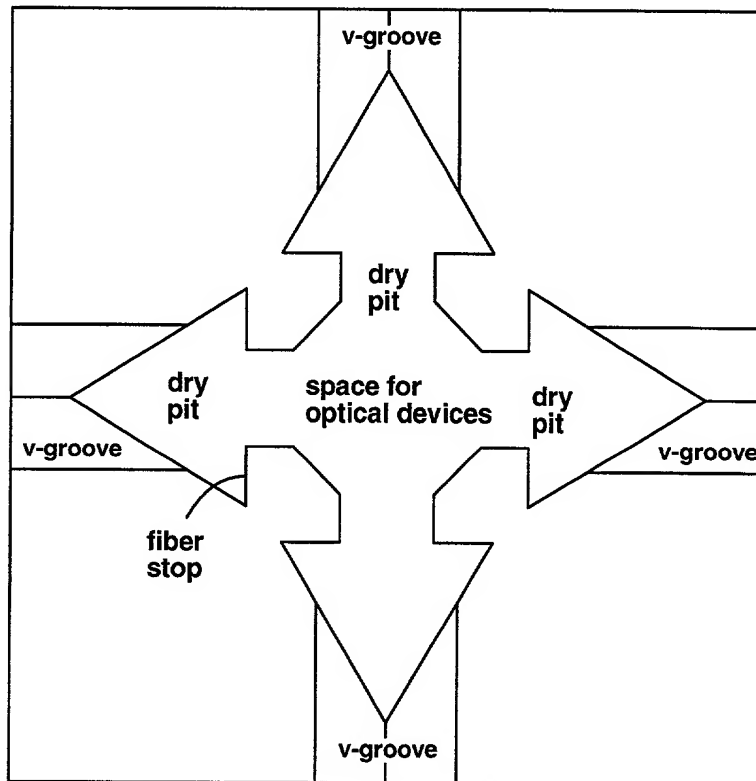


A four-V-groove device can also be made:

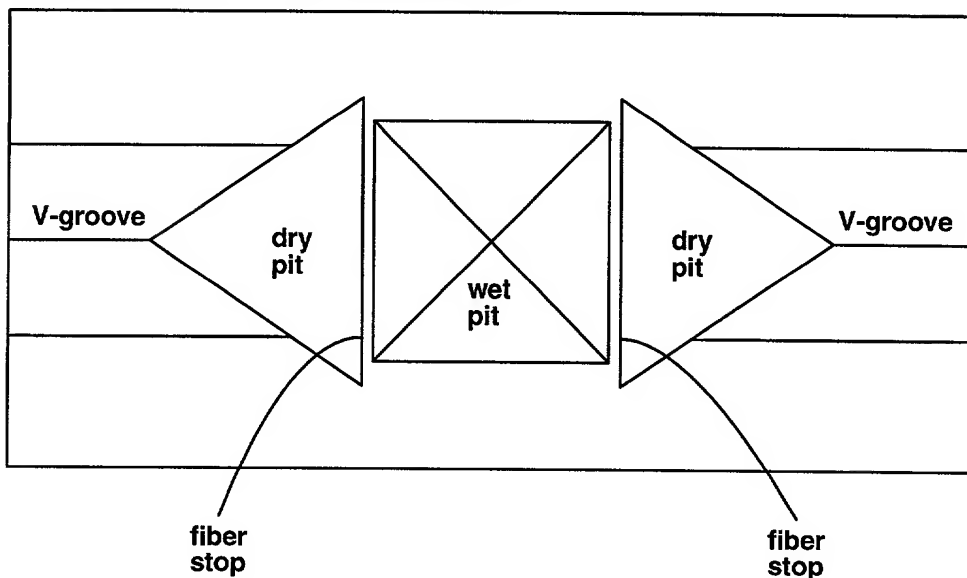


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A four-V-groove device can be made with a dry pit (instead of a wet pit) for holding optical devices. Each V-groove has associated fiber stops, and there is space in the middle of the dry pit for mirrors, micromechanical devices, filters, lenses and the like. For example, a microopticalmechanical device can be placed face down on the substrate so that optical devies are disposed within the volume of the dry pit.

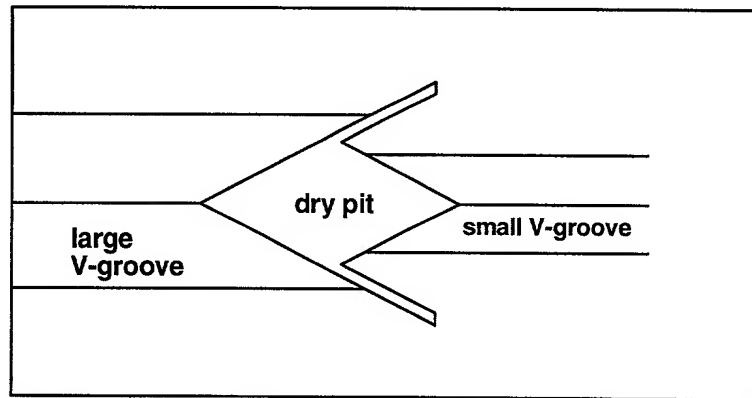


The wet pit can also be separate from the dry pits:

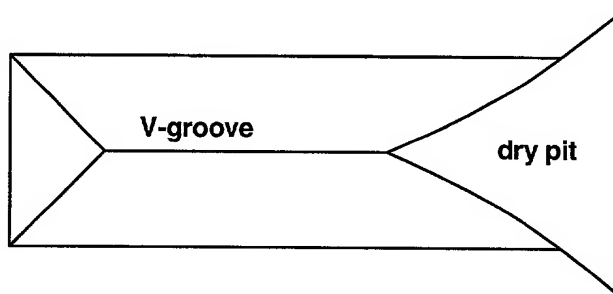
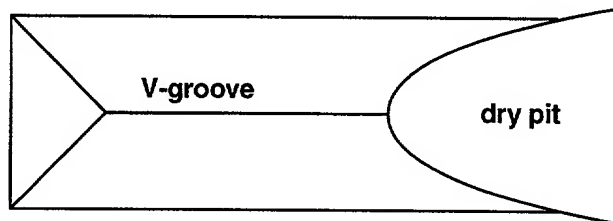


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The present invention includes another way to join V-grooves. A V-shaped dry pit can be used to join V-grooves. A V-shaped dry pit allows the V-grooves to be more closely spaced than a triangular dry pit.



In order to eliminate the wedge, the dry pit can have any shape that circumscribes the wedge area. For example, dry pits shown below can be used.

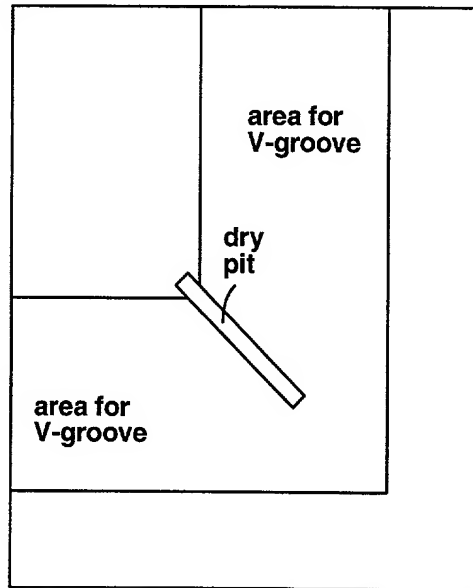


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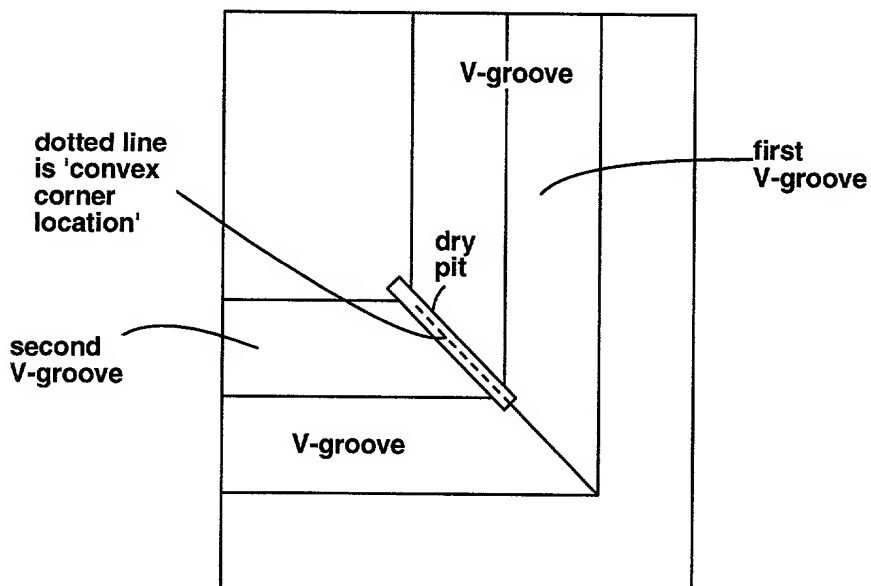
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The present invention can also be used to obviate corner compensation in V-grooves having a 90-degree bend. A dry pit is formed at the inside corner of the 90-degree bend.

- 1) Form a dry pit where the inside corner would be. The dry pit is conformally coated with a mask material.

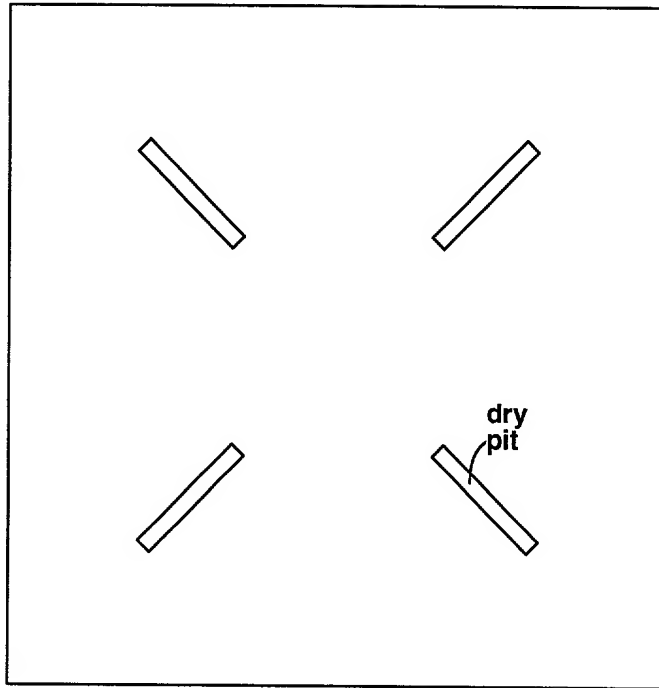


- 2) The V-groove is then etched. The entire 90 degree bend can be etched in a single step. The inside corner does not etch because it is protected by the mask material within the dry pit.

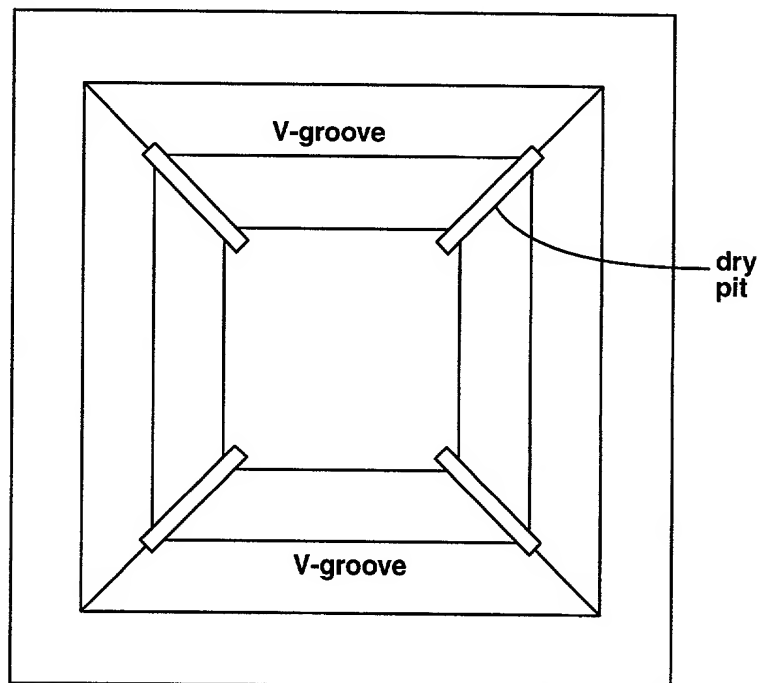


The corner-protection technique can be used to make a V-groove ring, for example.

- 1) Form 4 dry pits at locations of the convex corners



- 2) Etch V-groove ring

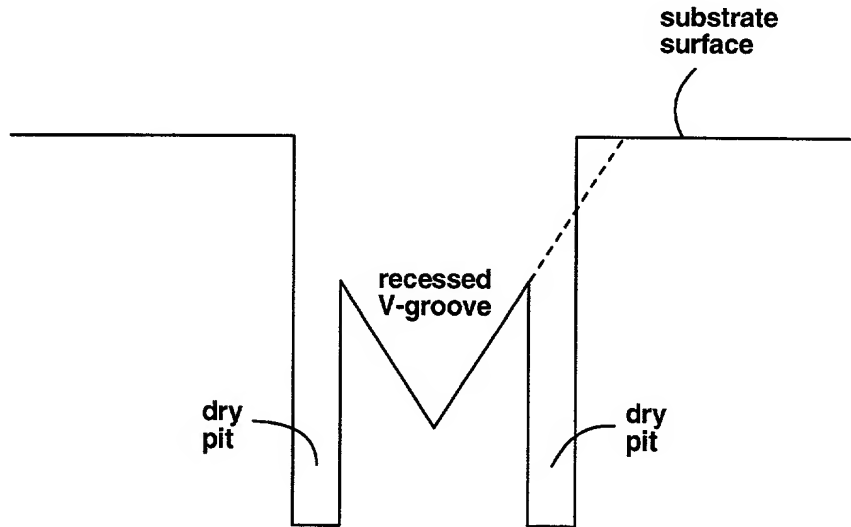


The diagram shows a cross-section of a structure with a large rectangular opening. A label 'dry pit' points to the interior of this opening. Another label 'Convex corner area' points to a small, angled protrusion on the right side of the opening's lower half.

A diagram of a dry pit, which is a rectangular structure with a V-shaped groove at the bottom. The diagram shows the pit from a top-down perspective, with the V-groove clearly visible. The label "dry pit" is written next to the structure, and "V-groove" is written twice, once for each of the two V-shaped sections.

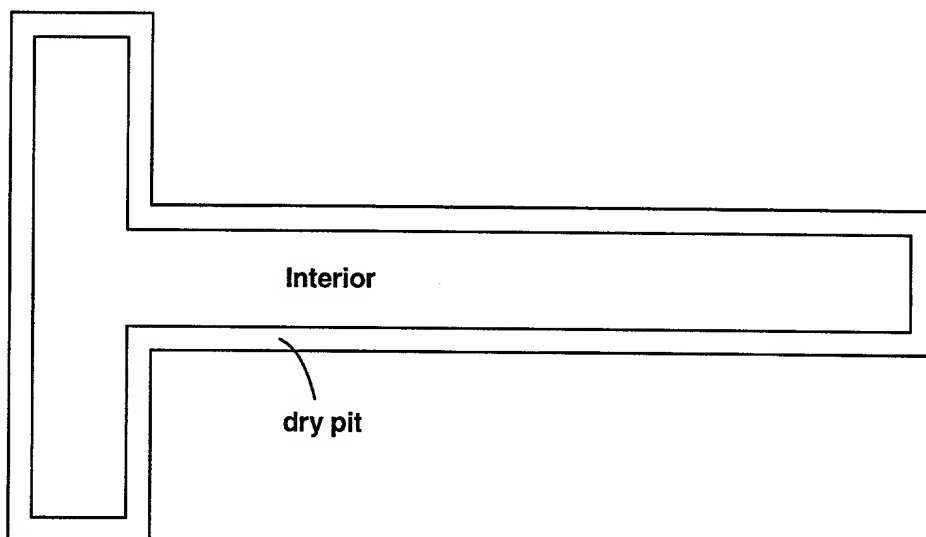
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The present invention can also be used to make 'recessed' V-grooves. Below is a cross-sectional view showing a recessed V-groove. The recessed V-groove cannot be made by etching deeply.



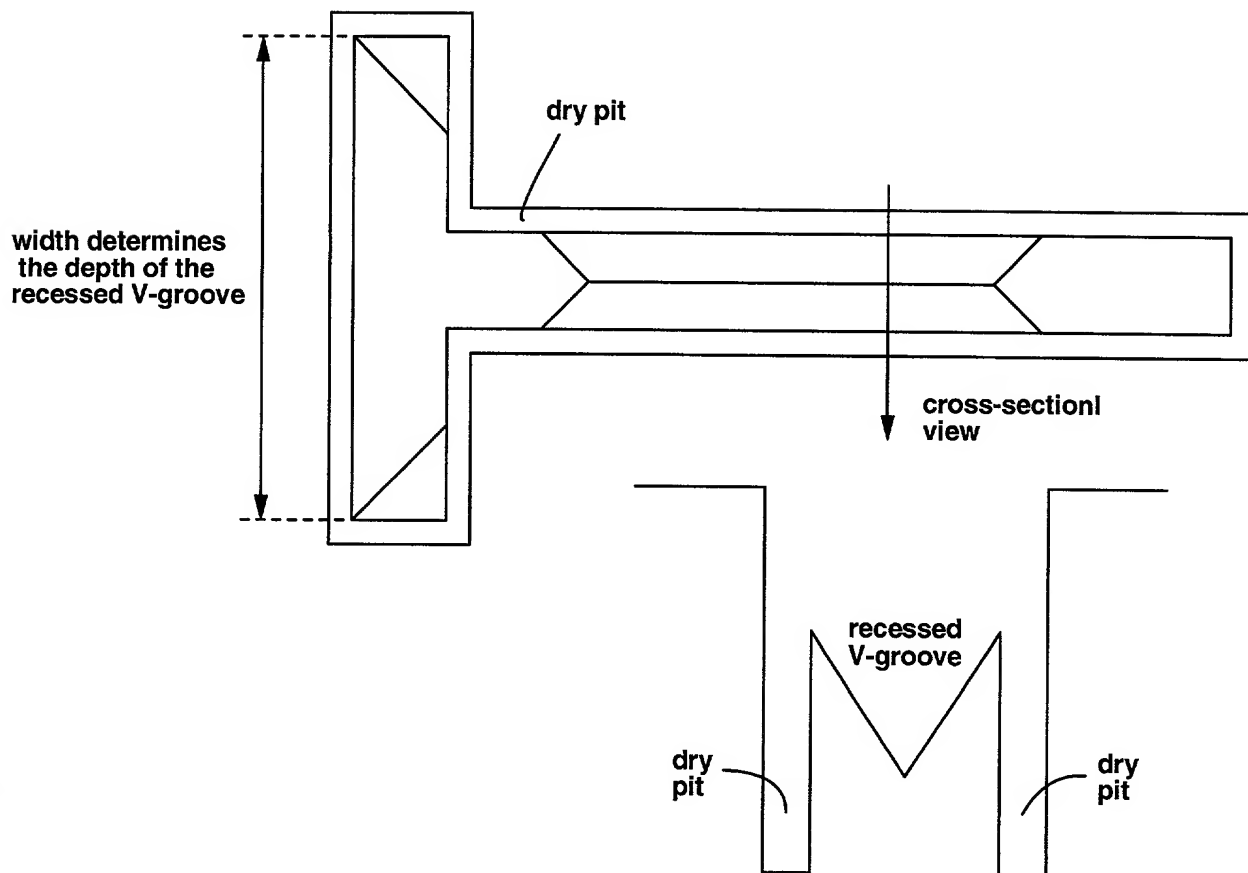
A recessed V-groove can be made by:

- 1) Forming a T-shaped dry pit ring. The interior of the ring is not dry etched.

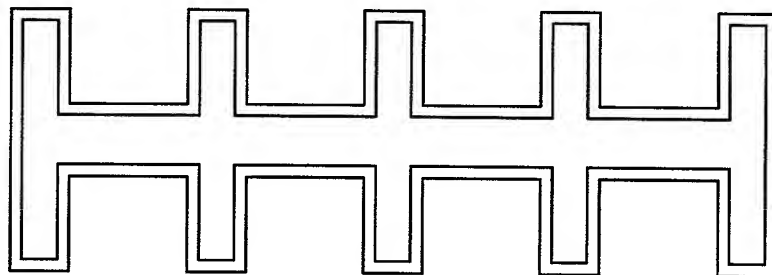


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2) Wet etching the interior of the dry pit ring.

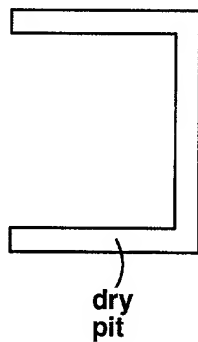


To make a long recessed V-groove, multiple wide portions can be incorporated into the dry pit ring.

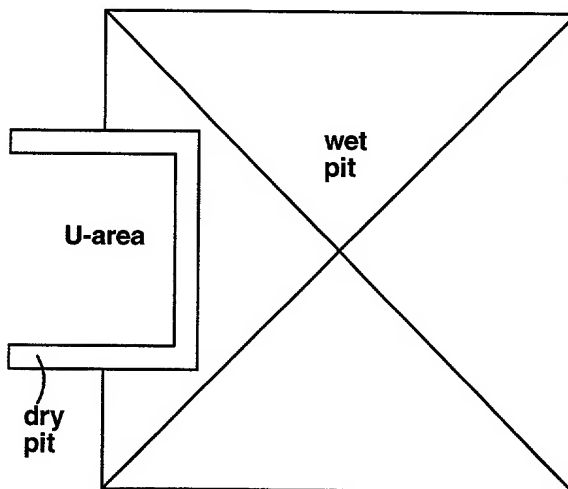


Another embodiment of the present invention provides a structure form placing a laser chip very close to a ball lens. This is desirable in a number of optoelectronic subassemblies (see for example, US patent 5,911,021).

- 1) Form a U-shaped dry pit.

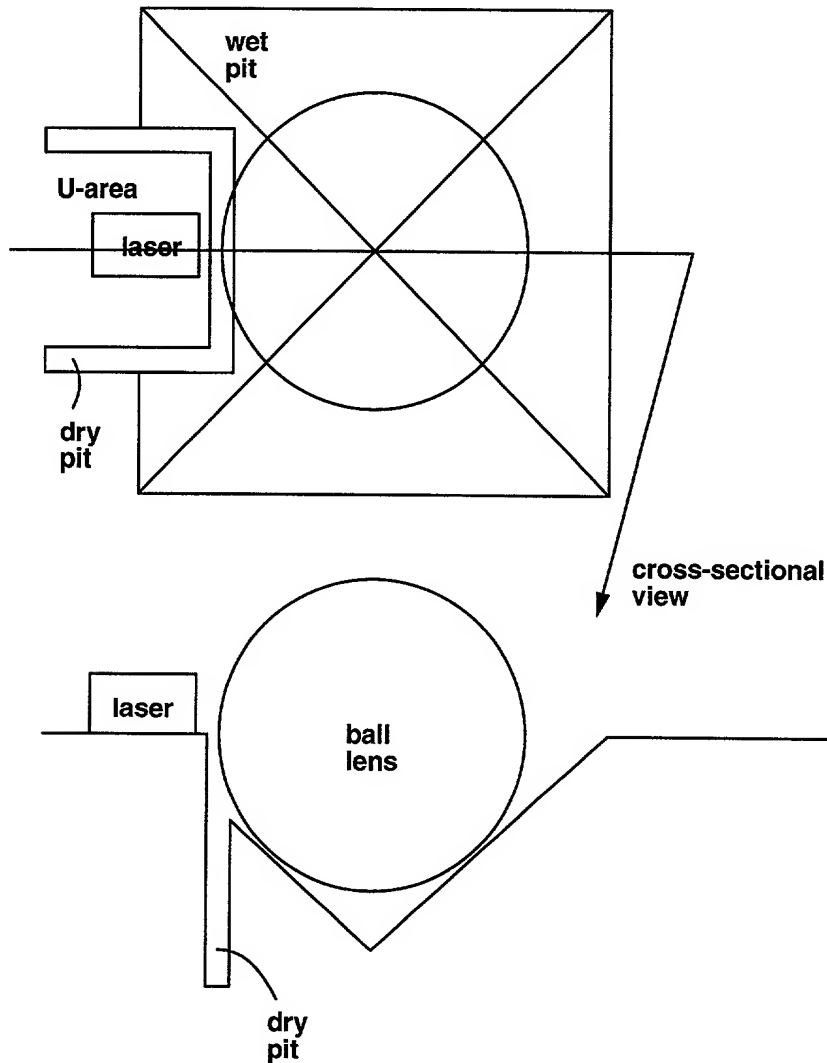


- 2) Wet etch a pit that intersects the U-shape. The U-area should not be wet-etched. The U-area is protected from the wet etch by the dry pit.



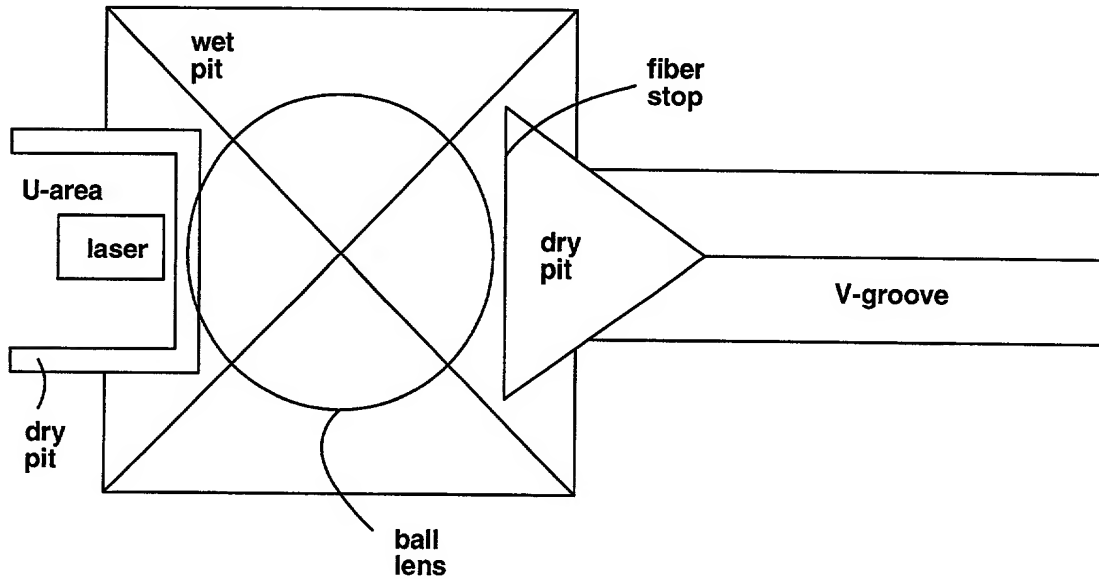
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- 3) When a laser is disposed on the U-area, and a ball lens is disposed in the wet pit, the laser can be quite close to the ball lens. Specifically, the laser can be closer to the ball lens in the present structure than in a conventional structure with just a wet pit and a laser disposed adjacent to the wet pit.

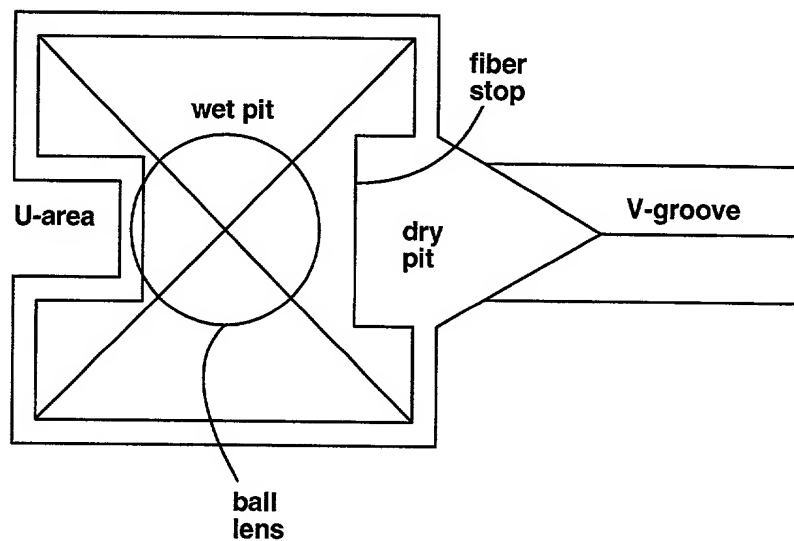


This structure provides increased heat dissipation for the laser, and allows the use of high-index ball lenses, thereby reducing spherical aberration.

The laser-lens structure can be combined with a V-groove by a dry pit (e.g. a triangular dry pit). An optical fiber can be disposed in the V-groove, and the dry pit can provide a fiber stop.



The dry pit can be a ring extending around the wet pit. In this case, the wet pit size is determined by the dry pit. The dry pit can include features for a fiber stop and eliminating the wedge in the V-groove.



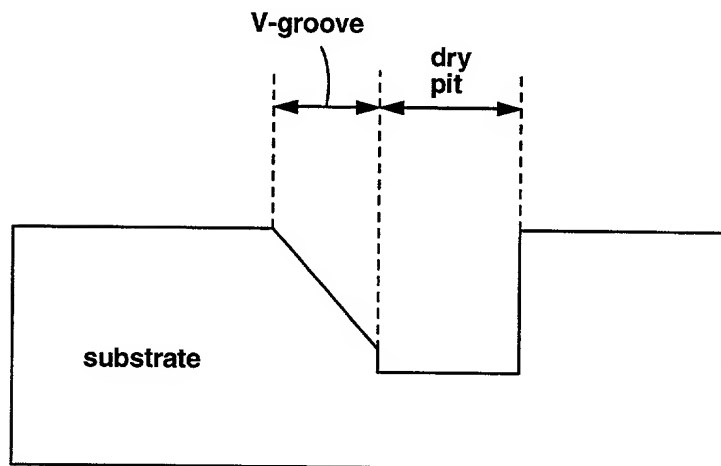
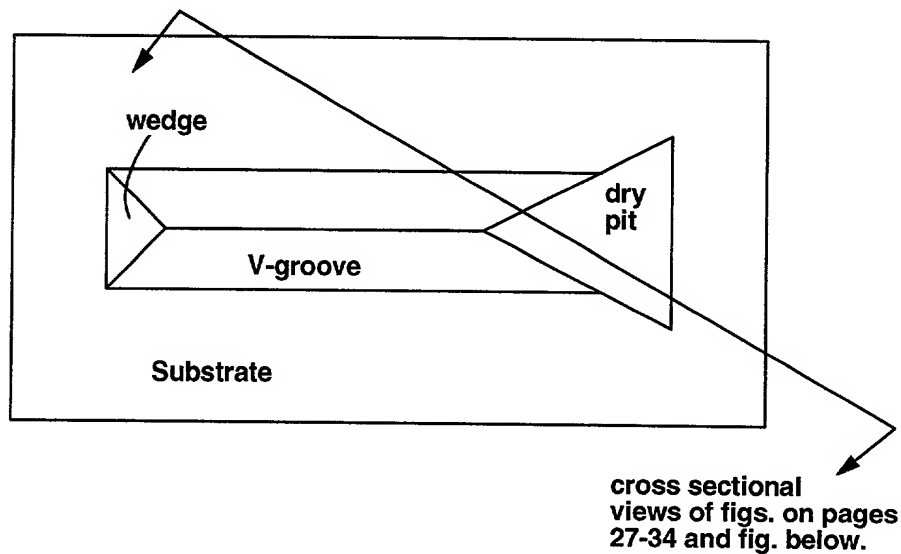
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The present invention may be used with SOI wafers so that the dry etch process has an etch stop.

The present invention can be used on <100> wafers and <110> wafers.

The present invention can be used with silicon and other materials such as GaAs, InP.

The figures on pages 27-34 are cross sectional views illustrating methods in the present invention. The cross sectional views are from a substrate etched as shown below. An exemplary cross sectional view is shown below, also.

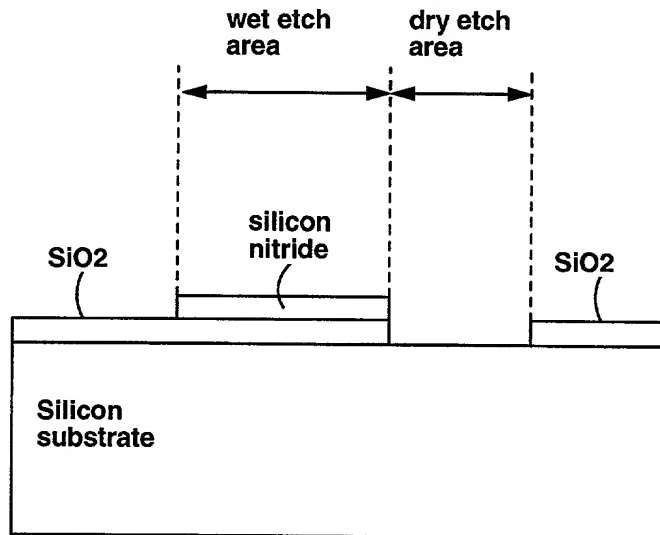


Combined wet and dry etching can be performed according to a number of different methods. The dry pit can be coated with CVD nitride or oxide, or can be thermally oxidized. The present invention can be used with silicon or other materials (e.g. GaAs) that can be dry etched wet etched (isotropic or anisotropic) and can be conformally coated with a mask material.

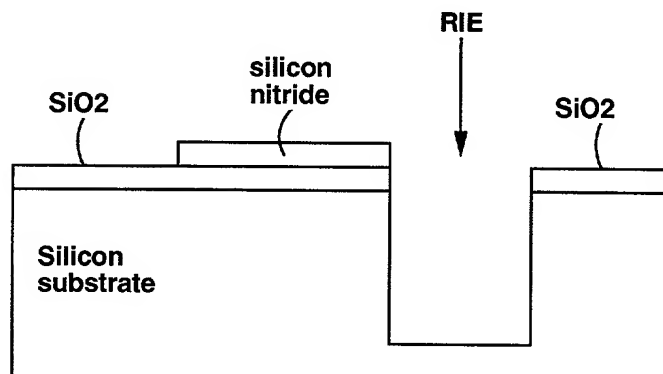
Below is a first embodiment for making the structures of the present invention:

Method #1

- 1) Start with a silicon substrate. Deposit and pattern an SiO₂ layer and a nitride layer. The SiO₂ layer should be thick enough to serve as a mask during the dry etch step. (e.g. the SiO₂ layer can be about 2 microns thick for a 100 micron deep dry pit. The patterns in the oxide and nitride determine the wet and dry etch areas as shown.

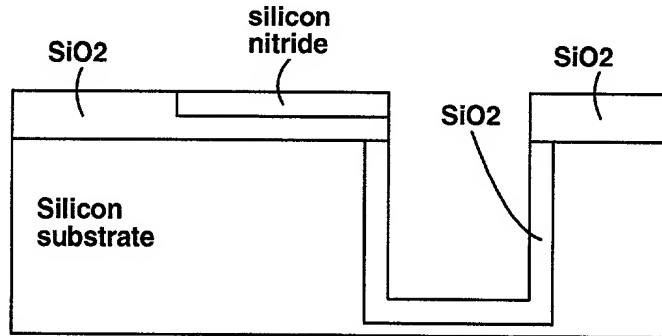


- 2) The dry pit is formed. The dry pit can be performed by reactive ion etching, plasma etching, ion milling or any other directional process.

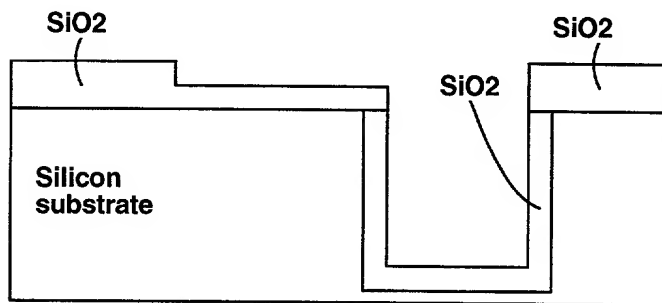


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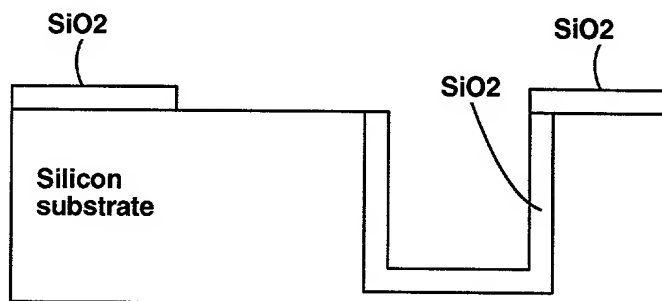
- 3)** The wafer is thermally oxidized. The sidewalls are necessarily oxidized in this step. The thermal oxidation step causes the oxide layer to thicken in areas outside of the nitride.



- 4)** The nitride is removed. This can be done with a wet etch.

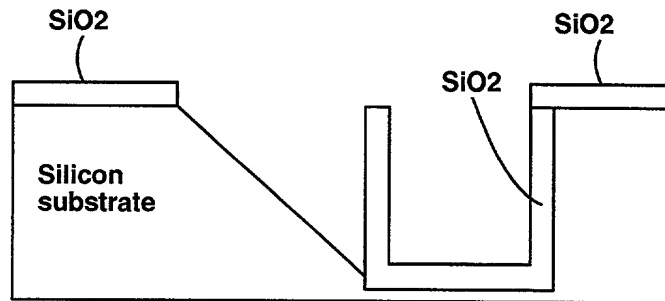


- 5)** A short duration oxide etch (wet or dry) removes the oxide that was under the nitride. Other oxide areas remain intact because they are thicker.

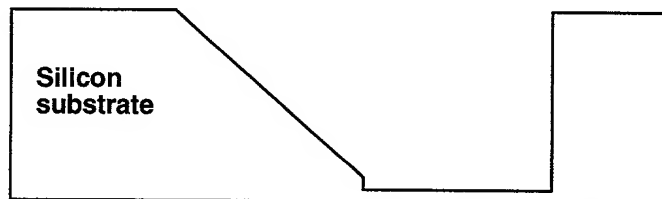


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- 6) The wafer is exposed to an anisotropic wet etch. KOH should not be used because it will attack the oxide. EDP or TMAH can be used because they will not attack the oxide as strongly.



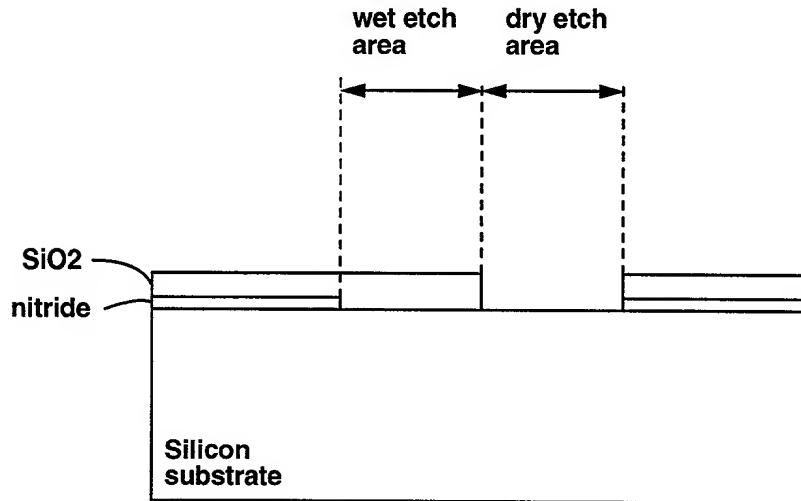
- 7) Optionally, the oxide mask material is removed. This can be done in a dilute HF etch.



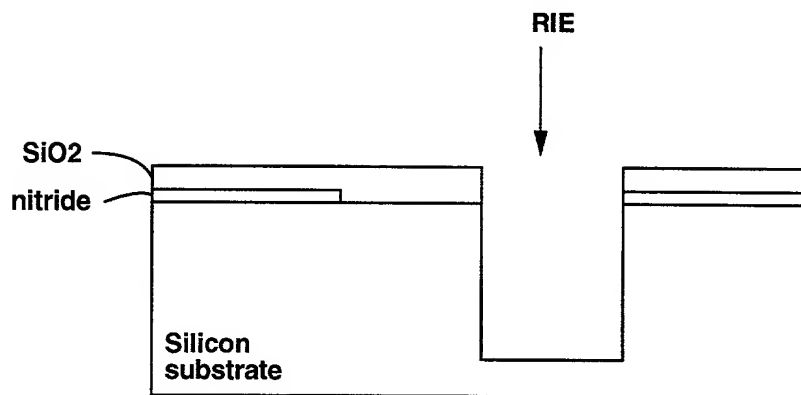
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Method #2

- 1) Deposit/pattern nitride layer, and then deposit/pattern oxide layer. The oxide layer can be thicker than the nitride layer. the oxide layer can comprise PSG or BPSG, for example. The nitride and oxide patterns determine the wet and dry etch areas as shown.

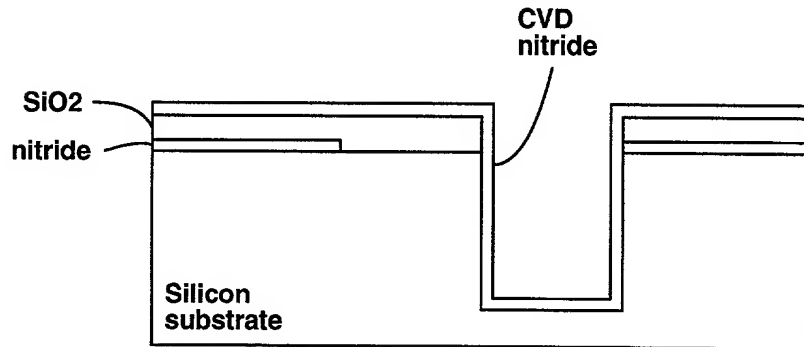


- 2) Etch the dry pit. This can be done with RIE, ion milling or similar processes.

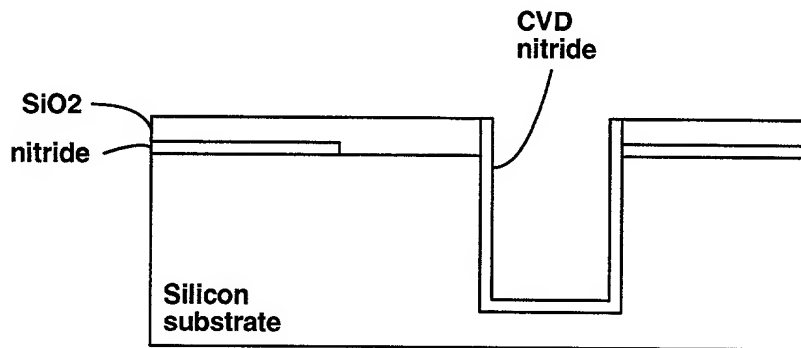


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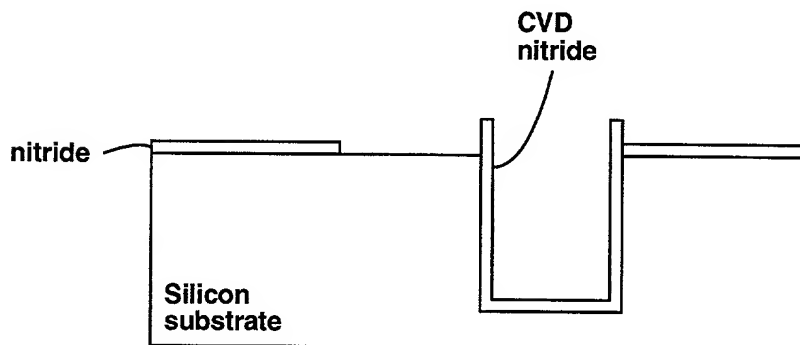
- 3) Conformally coat the wafer with CVD nitride. The dry pit is coated with nitride.



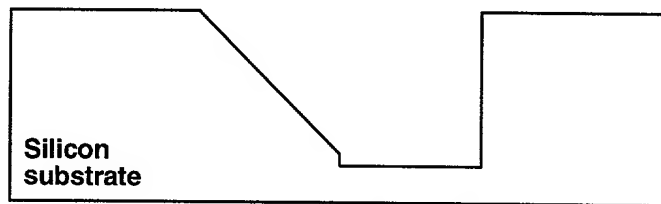
- 4) Planarize or polish the wafer so that nitride is removed from the top surface only.



- 5) Remove the oxide. This can be done with dilute HF.



- 7) Optionally, the nitride material is removed with etchant that does not damage the silicon.**

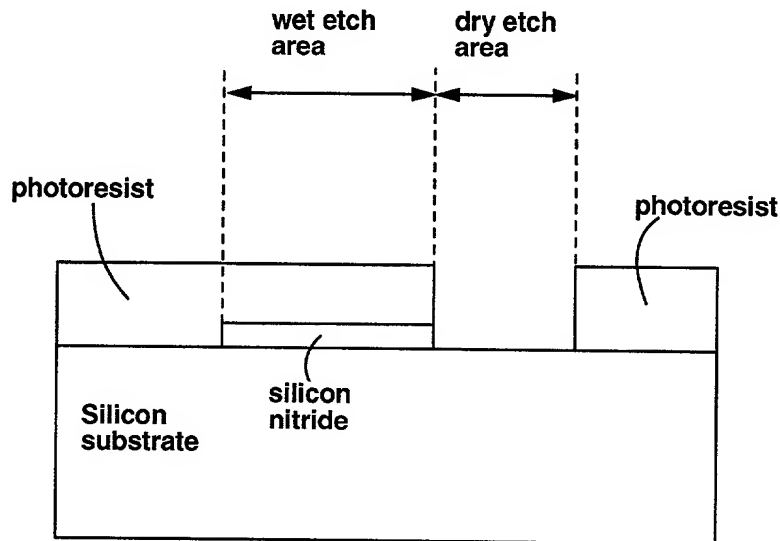


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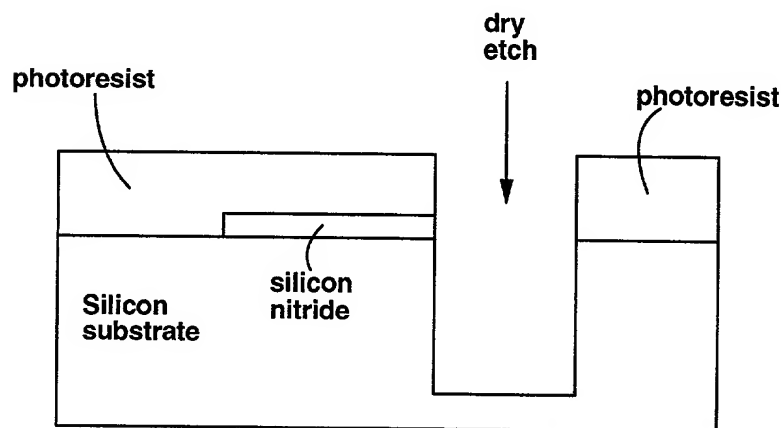
Below is a third method for making the structures of the present invention.

Method #3

- 1) Deposit and pattern a hard mask material that blocks oxide formation (e.g. silicon nitride), and then deposit and pattern photoresist. The dry and wet etch areas are defined as shown. The photoresist does not need to cover the entire hard mask area.

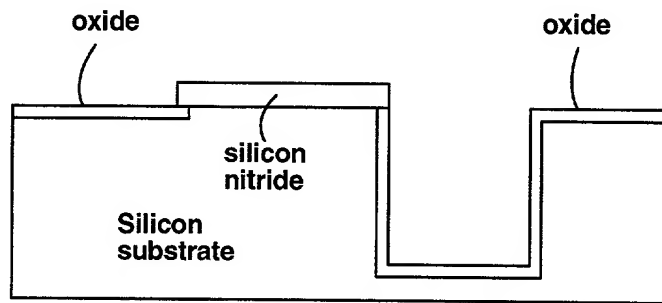


- 2) Dry etch the area exposed by the photoresist and hard mask.

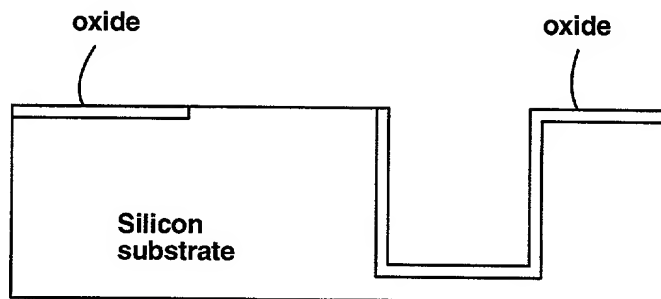


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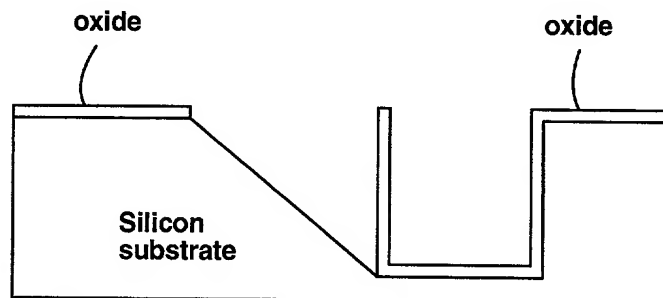
- 3)** Remove photoresist and oxidize. Oxide will not grow under the hard mask.



- 4)** Remove the hard mask.



- 5)** Wet etch with anisotropic etchant.



The oxide can be removed after step (5).